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Dynamic evaluation of a historic fountain under blast loading

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Abstract

The fountain in the center of the *Plaza de los Luceros* is one of the most important monuments of the city of Alicante (Spain). This modernist structure was built by the local artist Daniel Bañuls in 1930, and is composed of a central body and four horse sculptures. It has been re-paired several times in the early years of XXI century, even the monument was once totally dismantled, and reconstructed later, due to the works carried out during the construction of an underground railway station under the Plaza. The most frequent pathologies are superficial cracking and spalling because of the nearby road traffic, water from the fountain, and corrosion of the embedded steel elements of the fountain installation. Furthermore, blast-induced vibrations should be considered as another damage source, because every year for the city festivities several fireworks (called *mascletàs*) are held in the Plaza, near the fountain. The location of these *mascletàs*, typical in the east-coast of Spain, led to a public debate about the possible effects on the fountain's health. Temporary measures were taken to protect each horse sculpture during last years' *mascletàs*, and health monitoring was made to evaluate both the effectiveness of these protections, and the damages suffered by the monument. Several accelerometers were attached to the fountain itself and the ground (which is currently the slab of the lower station). The peak accelerations measured at the monument during a *mascletà* were around 0.4g. After a frequency analysis, the maximum accelerations exceeded the limits recommended in different European standards for low frequencies, in the range between 1 and 10 Hz. Therefore, these blasts may produce excessive damage on the fountain and some preventive measurements should be taken to preserve it.

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1. Introduction

Today heritage structures are exposed to dynamic loads that were not considered in their design, and are currently object of investigation for a proper simulation to include in structural models. Most of the damages suffered by architectural heritage are due to seismic actions, which require a specific retrofitting depending on the structural typology [1-2]. Nonetheless, the urban environment due to heavy traffic (road, railways, etc.) conditions induces also high vibration levels on nearby structures. Finally, there can be also vibrations related to blast loadings, e.g. tunneling construction in rock [3-4], or explosive devices due to deliberate attacks [5-7]. Regarding blast related vibrations, there are some recent studies that assess the different effects on structures, i.e. ground shock vibrations [8] and air-blast loads, or even the combination of both [9].

In this paper a case study of a heritage Fountain is studied, in which low weight explosives are detonated as a fireworks performance during the city festivities. Therefore the combined effect of ground vibrations and air blast pressures were measured and compared to different Standard recommendations to avoid damage to heritage structures.

2. Main characteristics of the structure

2.1. Construction and restorations

The fountain in the center of the Plaza de los Luceros is one of the most important monuments of the city of Alicante (Spain). Designed in a modernist style, this structure was built by the local artist Daniel Bañuls in 1930. It is composed of three different parts (Figure 1): a vase filled with water (with diameter equal to 20.6 m), a central body 16 m high, and four horse sculptures (hidden inside the protective screens seen in Figure 1).

The monument was once totally dismantled, and reconstructed later, due to the works carried out during the construction of an underground railway station under the Plaza (Figure 2). Therefore, the monument is currently supported by a RC slab made in prestressed concrete beams, as can be observed in the section included in Figure 2. Besides, before and after this reconstruction, the monument has been repaired several times in the early years of XXI century (2003, 2011 and 2015) due to different pathologies. The most frequent were superficial discoloration, cracking and spalling because of the nearby road traffic (this Plaza is one of the main traffic nodes of the city center), water from the fountain, and corrosion of the embedded steel elements of the fountain facilities. In the last intervention, some parts were retrofitted with glass fiber reinforced composites to enhance their durability.



Fig. 1. General view of the fountain of Plaza Luceros in Alicante (Spain).

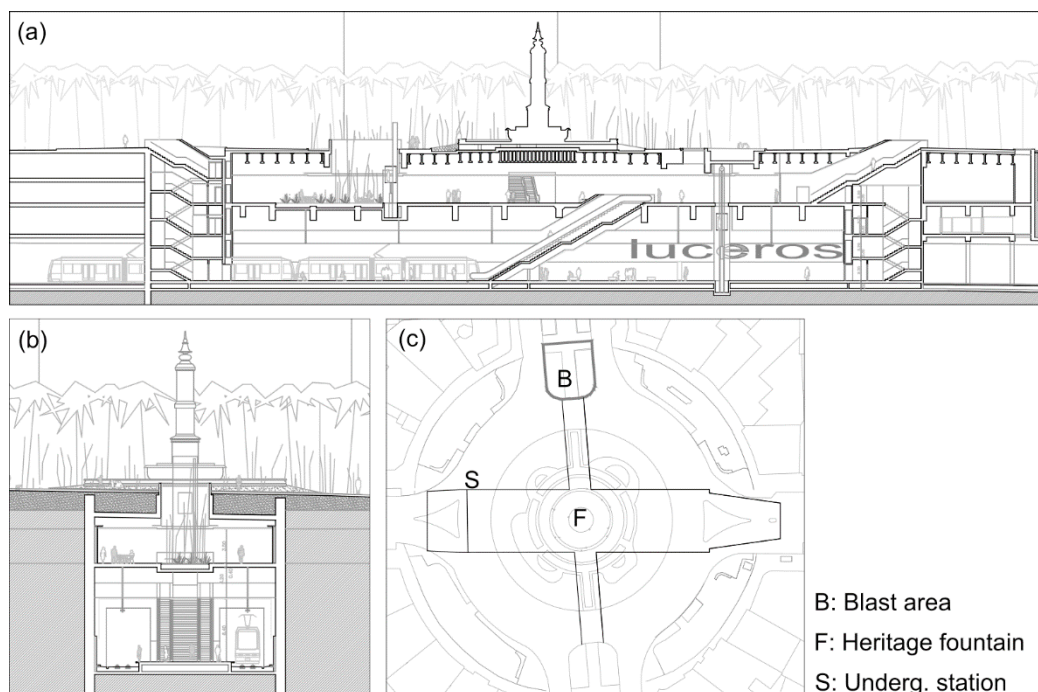


Fig. 2. Views of the underground station and fountain location: (a) W-E longitudinal section; (b) N-S section; (c) Plan view.



Fig. 3. (a) General view during fireworks blasting. (b) Explosive material distribution.

2.2. Blast induced loading

Furthermore, blast-induced vibrations should be considered as another damage source, because every year for the city festivities several fireworks (called *mascletàs*) are held in the Plaza, near the fountain. Figure 3(a) shows an example of these shows, while Figure 3(b) includes the preparation and placement of the explosive charges. The location of these *mascletàs*, typical in the east-coast of Spain, led to a public debate about the possible effects on the fountain's health. Recently, temporary measures were taken to protect the four horse sculptures during the

masclatàs. Around each sculpture a protective screen made in composite materials has been installed each year to protect them from blast induced vibrations (Figure 1).

Last year, a temporary health monitoring system was installed to evaluate both the effectiveness of these protections, and the possible damages suffered by the monument during these events. Table 1 includes the criteria of Spanish standard UNE 23381:1993 [4] to establish the admissible vibration levels of a structure due to blast induced vibrations. Different criteria are considered depending on the frequency, i.e. maximum velocity or displacement. Also, three different structural categories are defined, in which heritage structures can be considered as type III or II if they are especially sensitive to vibrations or not, respectively. In this case, because of the singularity of the structure a type III construction was considered. Similar criteria can be found in international standards [10-11], which set limits to peak particle velocity in the ground nearby the structure of analysis [3].

Table 1. Criteria for damage prevention of structures due to blasting, UNE 23381:1993 [4].

Frequency (Hz)	2-15	15-75	>75
	Velocity (mm/s)	Displacement (mm)	Velocity (mm/s)
Type I (Light structures in Steel or RC)	20	0.212	100
Type II (Regular buildings)	9	0.095	45
Type III (Heritage structures sensitive to vibrations)	4	0.042	20

3. Experimental setup

In order to assess the durability of the fountain, accelerations levels at six different points were measured. A total number of eight accelerometers were used, four attached directly to the fountain (South Façade A1-A2, East Façade A3-A4), a triaxial accelerometer attached to a concrete slab directly on the ground (A5-A6-A7) and another vertical accelerometer on the ground (A8). Sensors A1 and A3 had a sensitivity of 10000mV/g, while all the rest had a sensitivity of 1000 mV/g. The charges were located in the North part of the fountain, see Figure 2(c), and according to the City Hall regulations for the competition a maximum explosive weight of 80 kg could be installed, and should be completely fired for a total duration of at least six minutes and thirty seconds. Accelerations were recorded at 500 Hz using PCB signal conditioners and data acquisition equipment Kyowa Model PCD-320.

Table 2. Maximum accelerations recorded at each position.

Accelerometer	A1	A2	A3	A4	A5	A6	A7	A8
Direction	N-S	N-S	E-W	E-W	N-S	E-W	V*	V*
Location*	F	F	F	F	G	G	G	G
Peak acceleration (m/s ²)	3.16	9.37	3.17	5.05	2.13	2.99	4.10	6.92

* F: attached to the fountain; G: attached to the ground; V: vertical accelerations.

4. Results and discussion

Figure 4 includes four time-functions for accelerations at different sensors during all the fireworks show. Initially the explosives are detonated at different frequencies. In the middle part the intensity of almost all accelerations was lower, and during the final part (which name can be translated as earthquake) there was an amplification of the dynamic response, and maximum accelerations were registered at all sensors. The corresponding peak accelerations for each accelerometer have been included in Table 2.

Afterwards, each signal was analyzed in the frequency domain, and RMS accelerations were assessed for each frequency. Thus, in Figure 5, RMS acceleration for the triaxial device (A5-A6-A7) is shown, and compared to limit values included in different European standards, i.e. UNE 22381:1993 [4] and DIN 4150 [10]. Due to the characteristics of the fountain a Type III structures can be assumed according to [4]. This limit is similar to the curve for the German standard [10]. For the analyzed frequencies, between 1 and 20 Hz, there level of ground vibrations

was too high for frequencies below 20 Hz according to Spanish standard. Similar results were observed for all sensors, hence additional measures should be taken in order to avoid further damage to the monument. Furthermore, a detailed numerical analysis should be made in order to assess the influence of the concrete slab of the station on the vibrations. Despite there aren't any data prior to the construction of the underground station, the location of the blast area, directly on the slab could increase the wave's transmission velocity. Therefore two measures should be considered, first a relocation of the point of blast, so it doesn't interfere with the station's structure. And second, if this option is not possible, a platform can be cast between the charges and the pavement, hence additional dampers can be used to control vibrations related to these low frequencies, which showed values above guidelines and standards.

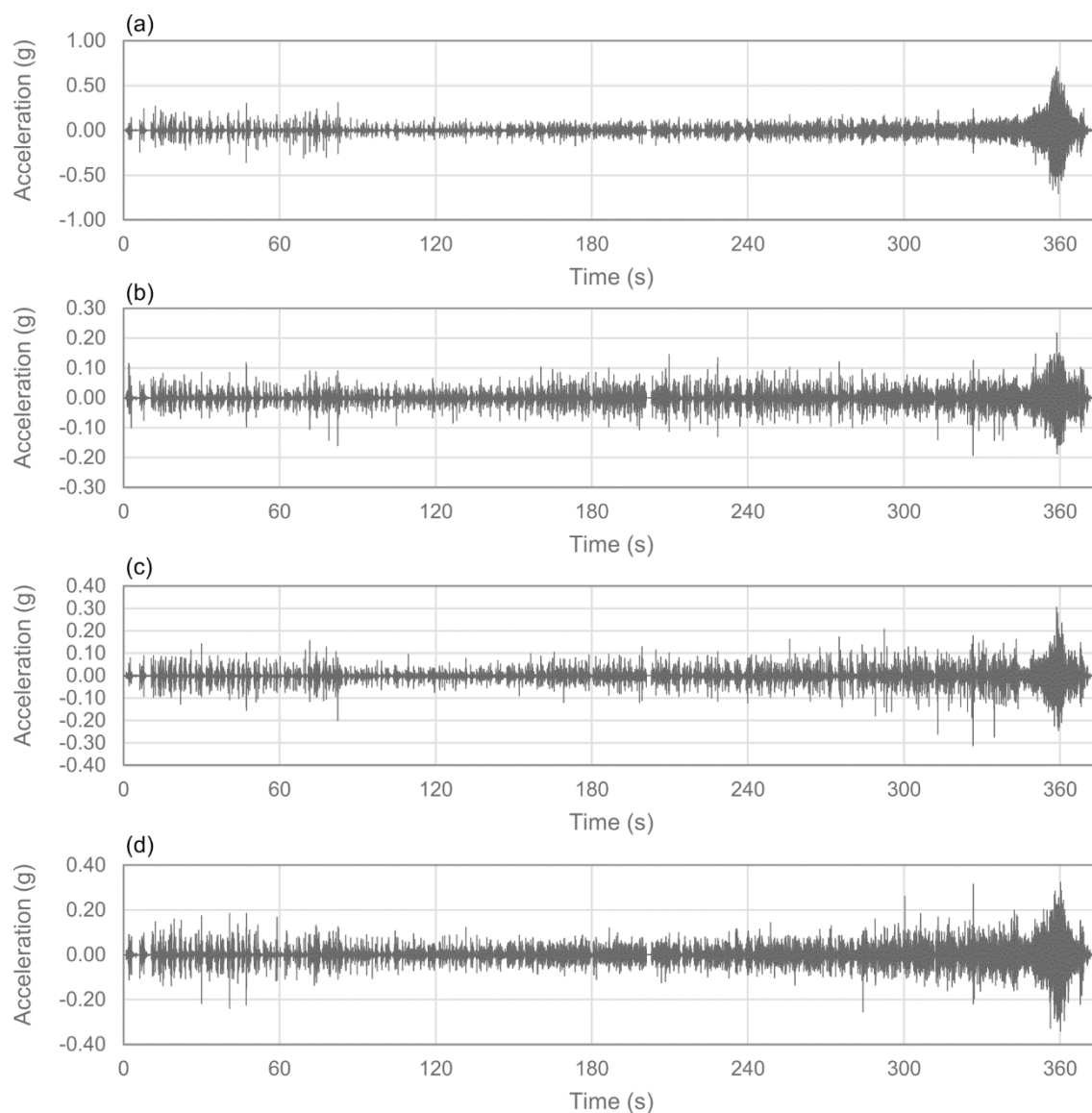


Fig. 4. Accelerations registered at different sensors: (a) A8; (b) A5; (c) A6; (d) A1.

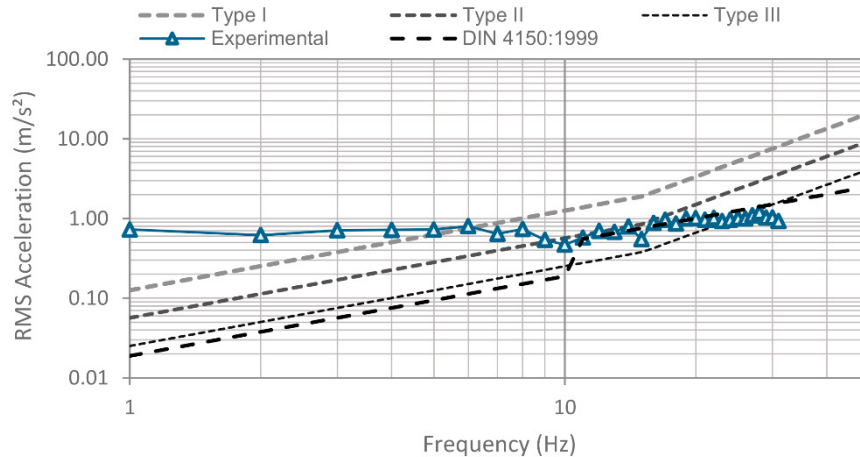


Fig. 5. RMS acceleration for each excited frequency at ground level (dashed lines correspond to different standard limits for damage control)

5. Conclusions

A dynamic analysis was performed in a historic monument of the city of Alicante, which every year is exposed to seven fireworks shows. Each one is composed of up to 80 kg of explosives, which are detonated during a six-minute performance. The acceleration levels registered, both at ground level and 3 m high onto the monument, were beyond the recommended limits of different standards. Hence, the protective screens around each horse statue is not effective to guarantee its conservation. The ground vibrations transmitted directly from the detonation point, and through the RC slab of the underground station are more important than the pressure effect of airblast charges. Therefore additional measures should be considered.

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